LASERS FOR POWER BEAMING

Laser Science and Engineering Group

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Support from: NASA MSFC, ARO

Outline

1. Why high peak power and high average power?

2. Do fundamental laws allow high peak power and high average power - in one system?

3. If high peak power and high average power are allowed what are the primary obstacles?

4. How might these obstacles be overcome?

Examples of terrestrial and space based systems

Barriers are serious, but more practical in character than fundamental

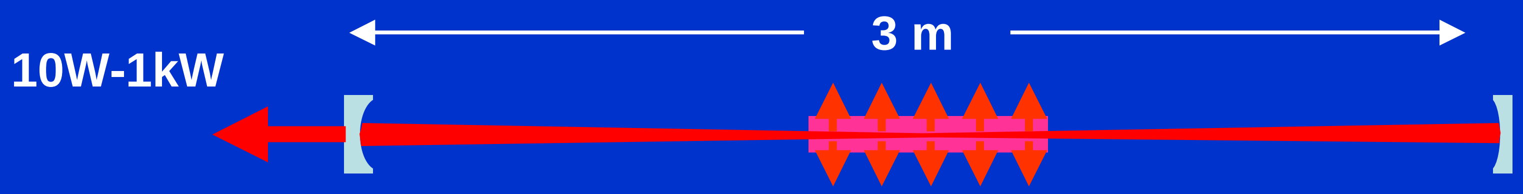
- **Need a substantial source of power**
- **Need novel thermal management**
- **Need unprecedented level of control**

Thermal distortion

B integral related distortion

Material damage

Heat extraction

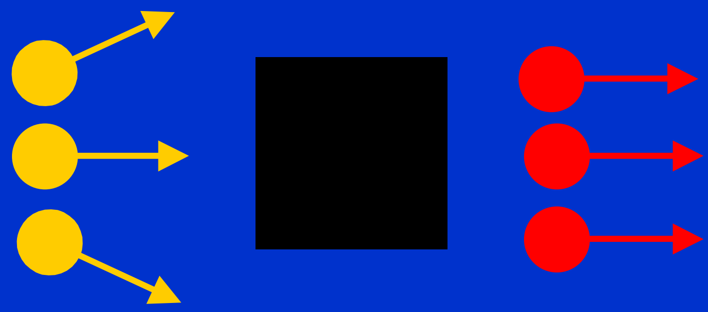


$$z_o = \pi w_o^2 / \lambda$$

Saturation intensity ~ 1 kW/cm^2

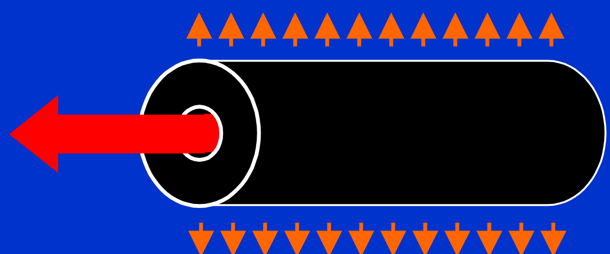
Some changes appear to be needed in the typical approach to modelocked lasers

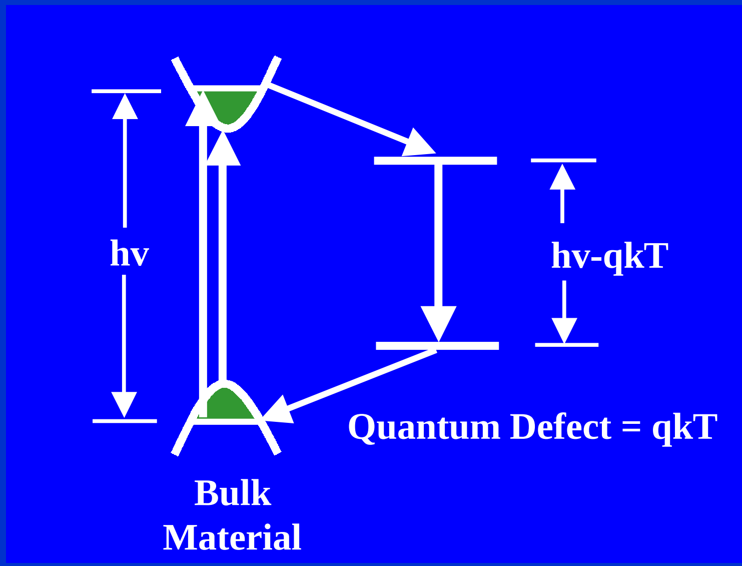
Fundamental Limit Perspective



The modelocked laser, in essence, increases the coherence of photons

The task: Move the waste heat, which must be at least ln2kT per photon, out of the laser system without hindering the coherence enhancing process





Unavoidable Quantum Defect

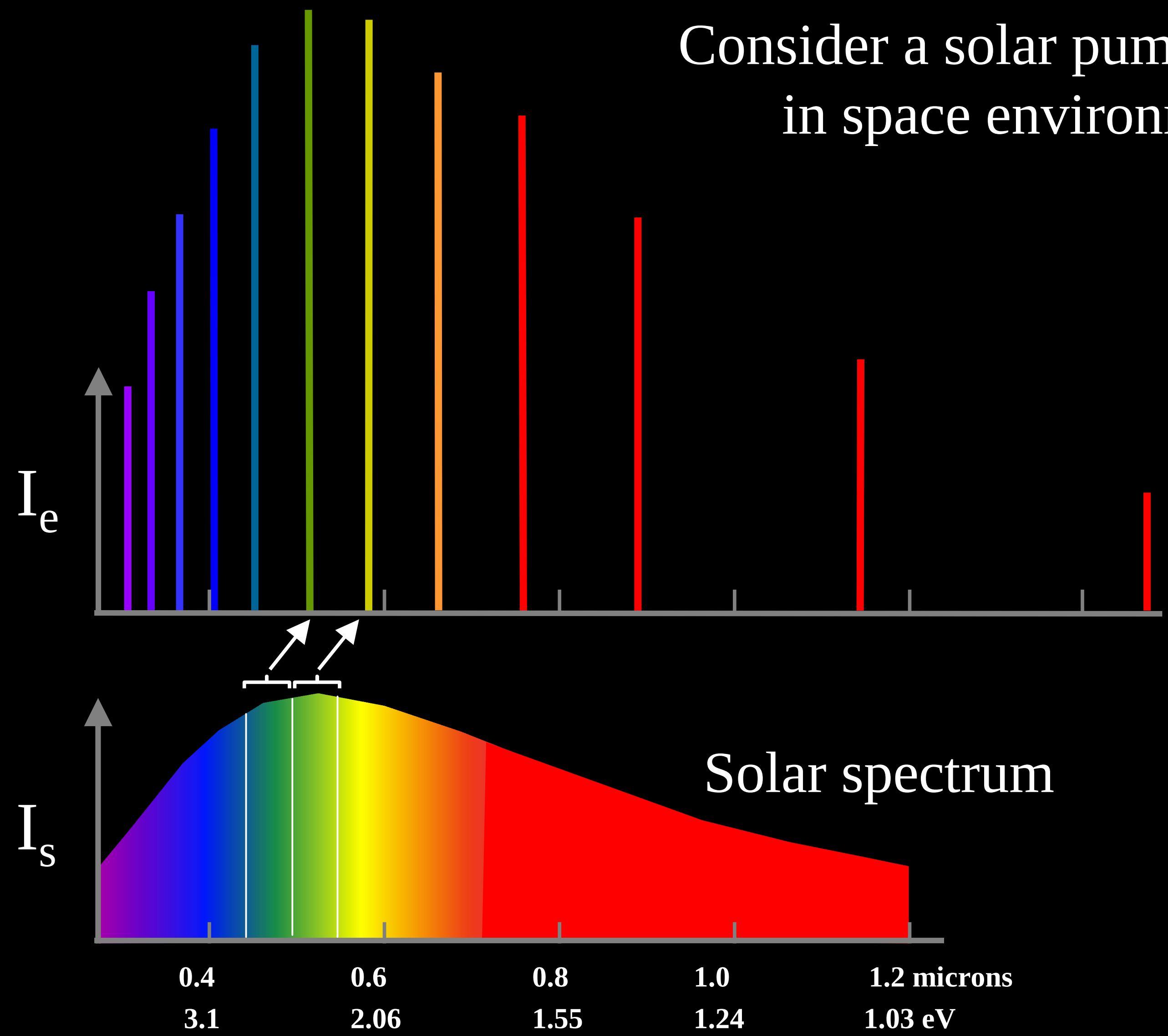
Efficiency is

$\eta = 1 - qkT / h\nu, \quad \ln 2kT < q < 10$

η can approach 98%

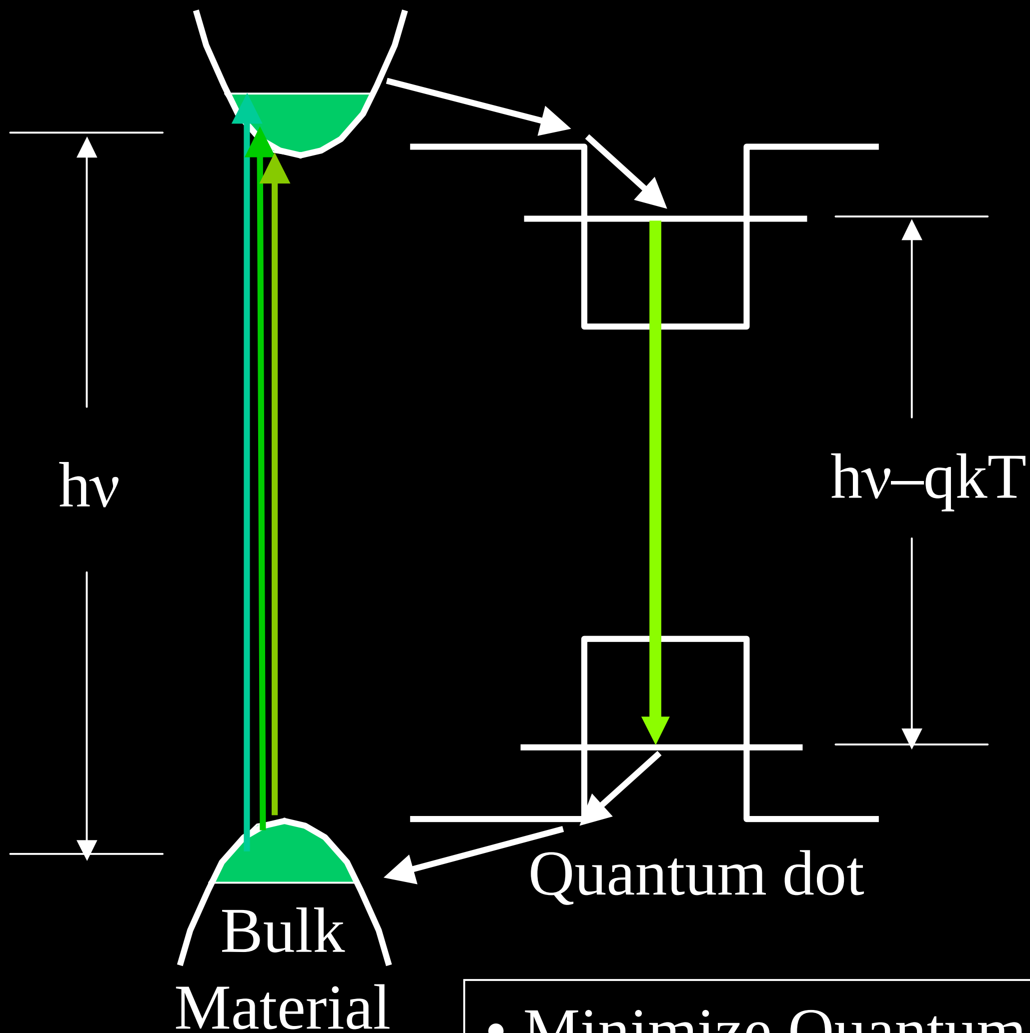
Lower temperature offers advantages

Consider a solar pumped laser in space environment



• Minimize Quantum Defect
• Achieve Laser Threshold

Quantum Dot enabling technology



$$\boxed{\sigma \cdot I_{\mathbf{pump}} \cdot \tau - \alpha_{\mathbf{loss}} > \mathbf{0}}$$

$\tau_{qd} = 3x10^{-9}$ s

$I_{sun} \leq 100 W/cm^2$

$\therefore$ need large cross section σ

Quantum dot cross section
$\sigma_{qd} \sim 4x10^{-13} cm^2$
Compare: $\sigma_{Yb} \sim 10^{-22} cm^2$

- Minimize Quantum Defect
- Achieve Laser Threshold

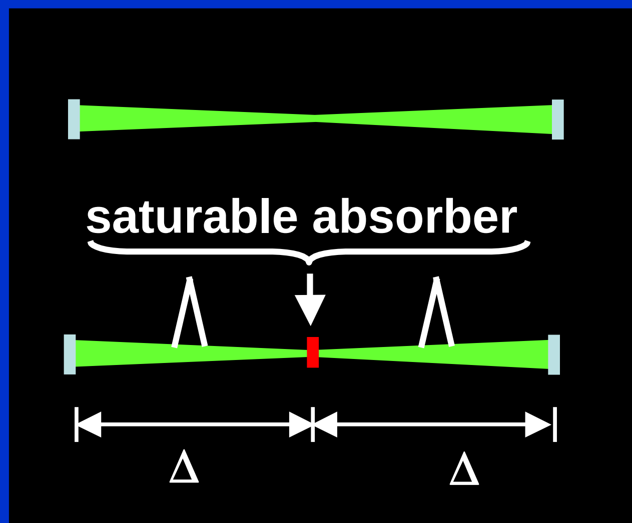
Frequency Space Modelocking

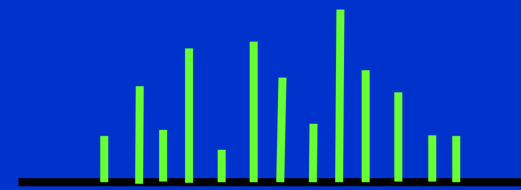
no frequency

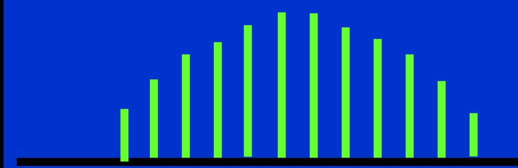
modelocking

frequency

modelocking

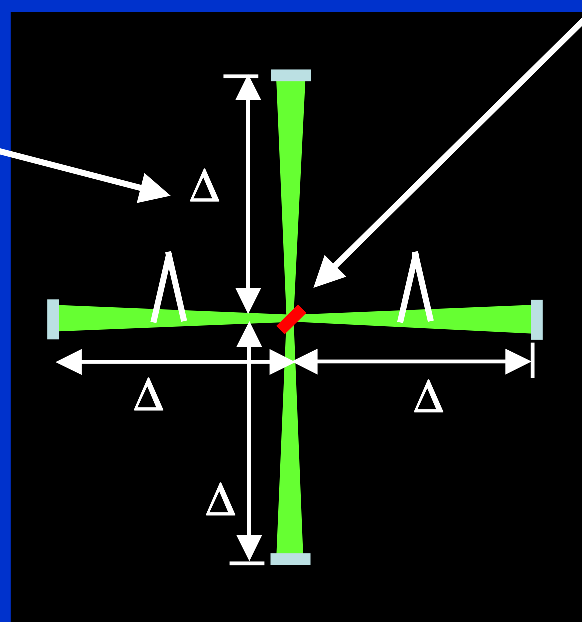


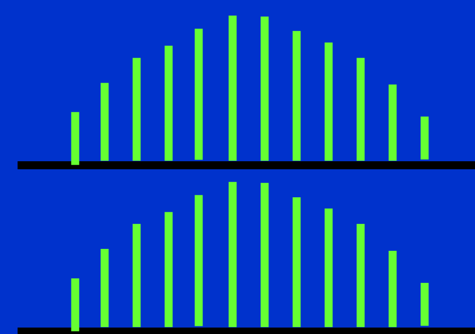




Slow mechanical control of Δ (300 Hz bandwidth)

Fast (THz) nonlinear optical locking of the optical phase



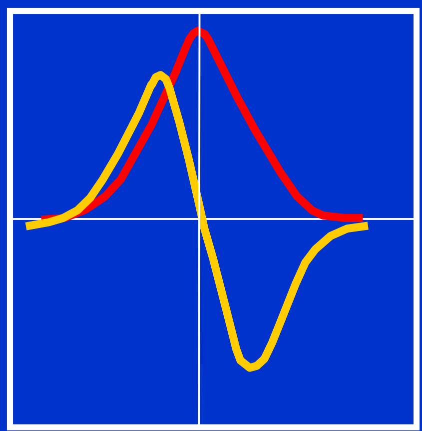


Frequency Space

Modelocking

Why high peak power and high average power?

- e.g., access to space
- economical and environmentally friendly



One more factor of two

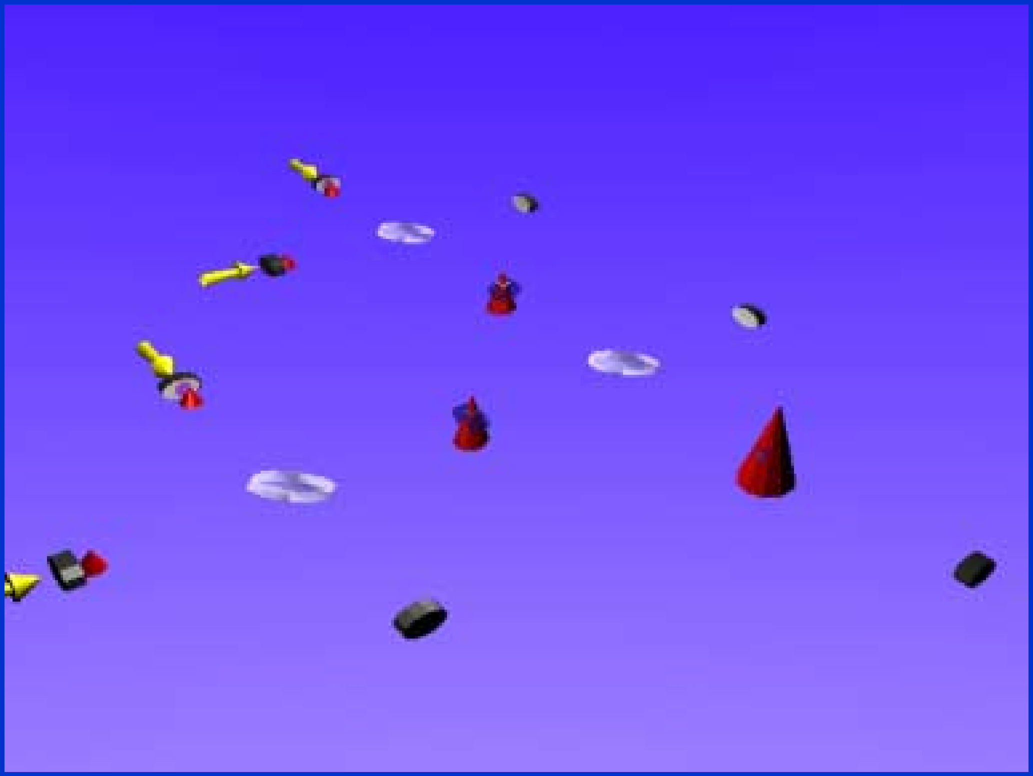
At 10^{15} Watts/cm^2 one obtains E~10^9 V/cm, proton accelerated for a half cycle accesses

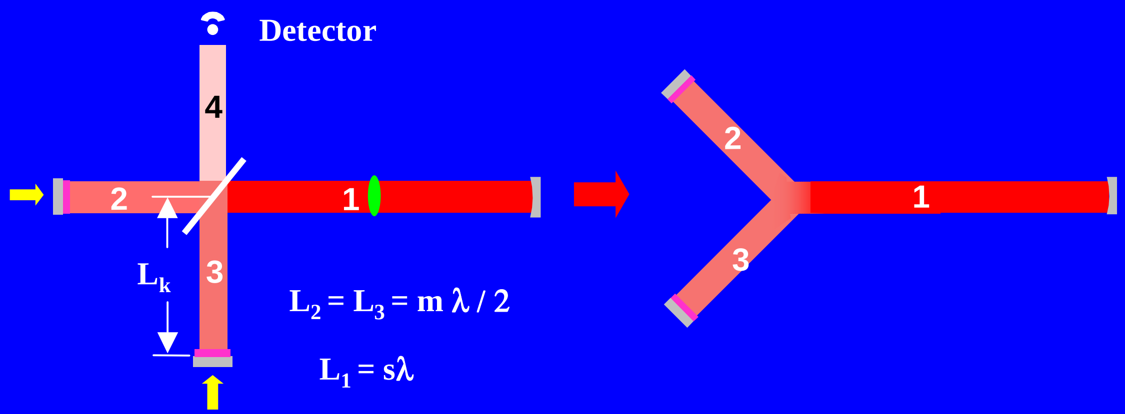
$v = eE/m_p$ ~10,000m/sec

- Monocycle pulse to half cycle pulse
- Yields escape velocity
- 1 GW of average optical power converted to thrust lifts 1 Metric ton to orbit

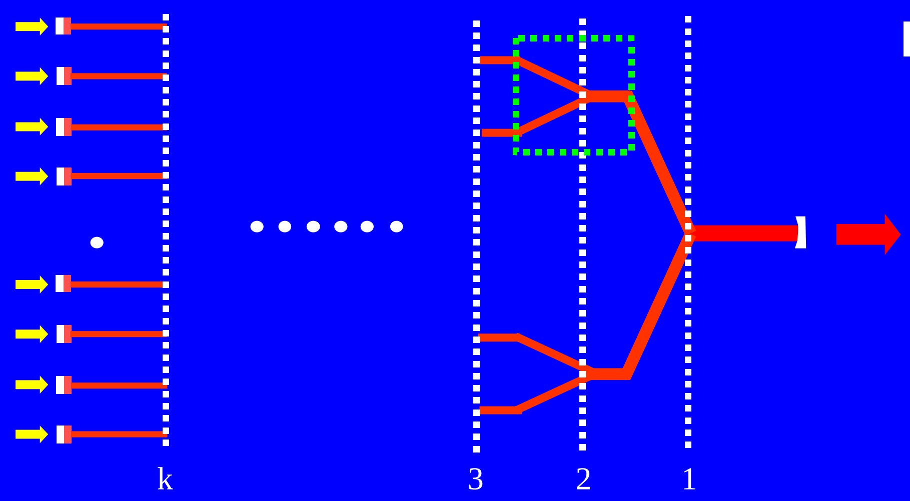
•"Based on time-space reciprocity, the pulse transformation that is due to diffraction can be reversed, e.g., by reflection of a pulse from a spherical concave mirror". A. Kaplan, JOSA B 15 951-956 (1998).

•Unipolar solitons from Maxwell-Bloch equations, R.K. Bullough and F. Ahmad, Phys. Rev. Lett. 27, 330 (1971).





Multiaxis-
multimode
laser



The Thin Disk Laser Structure

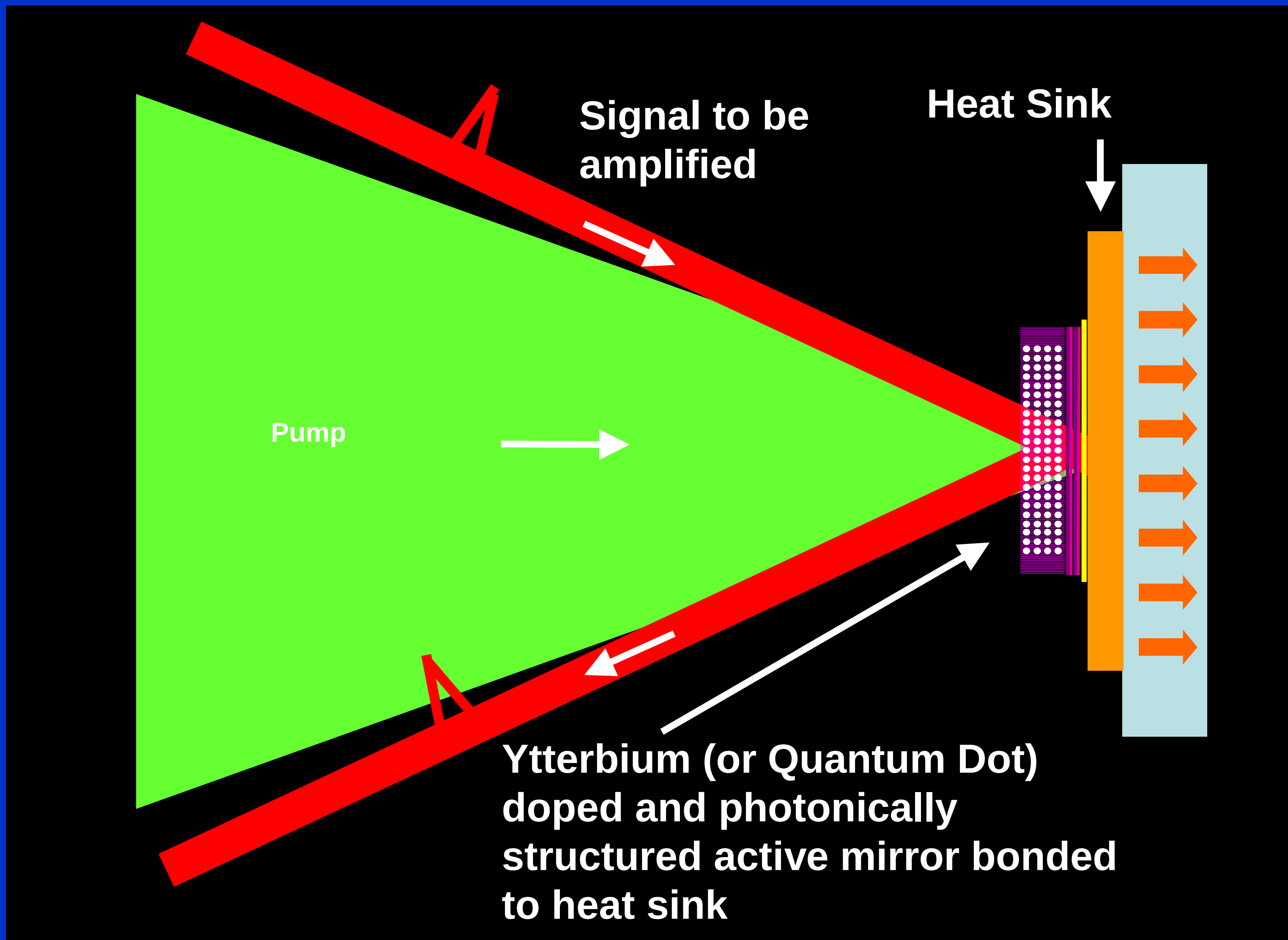
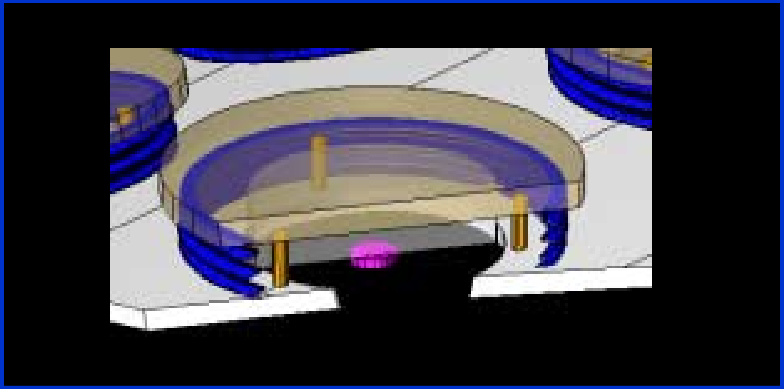
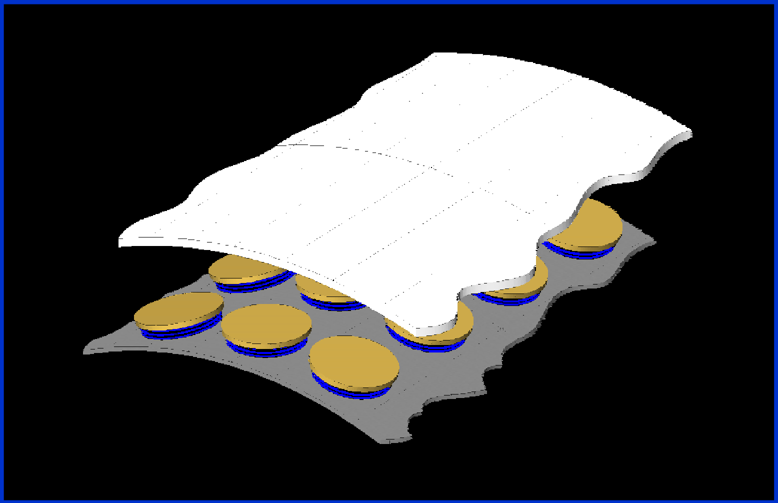


Fig. 4: Thin Disk Active Mirror, including layout of pump and probe pulses

Phase Change Cooling

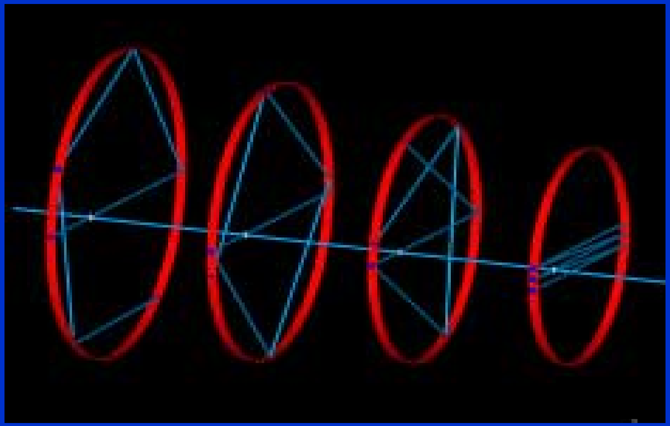


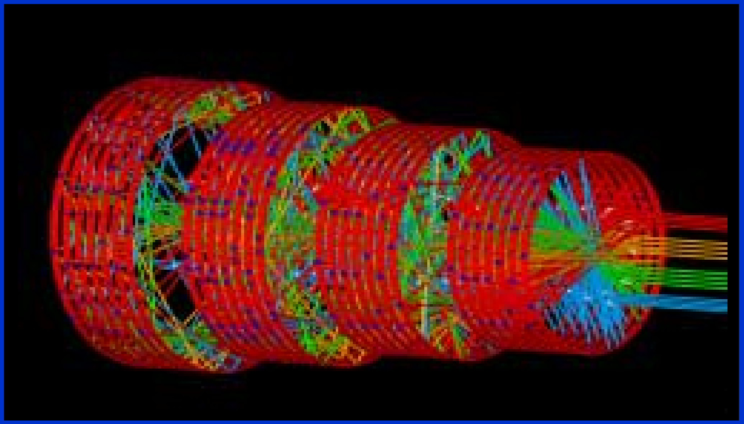
An active mirror (purple) is mounted on a heat sink (transparent brown). This assembly is oriented and translated by three transducers. A flexible seal (blue) allows motion while providing a hermetic seal between the exterior annular region (see (b) below) containing the liquid coolant and the interior region containing the optical fields.

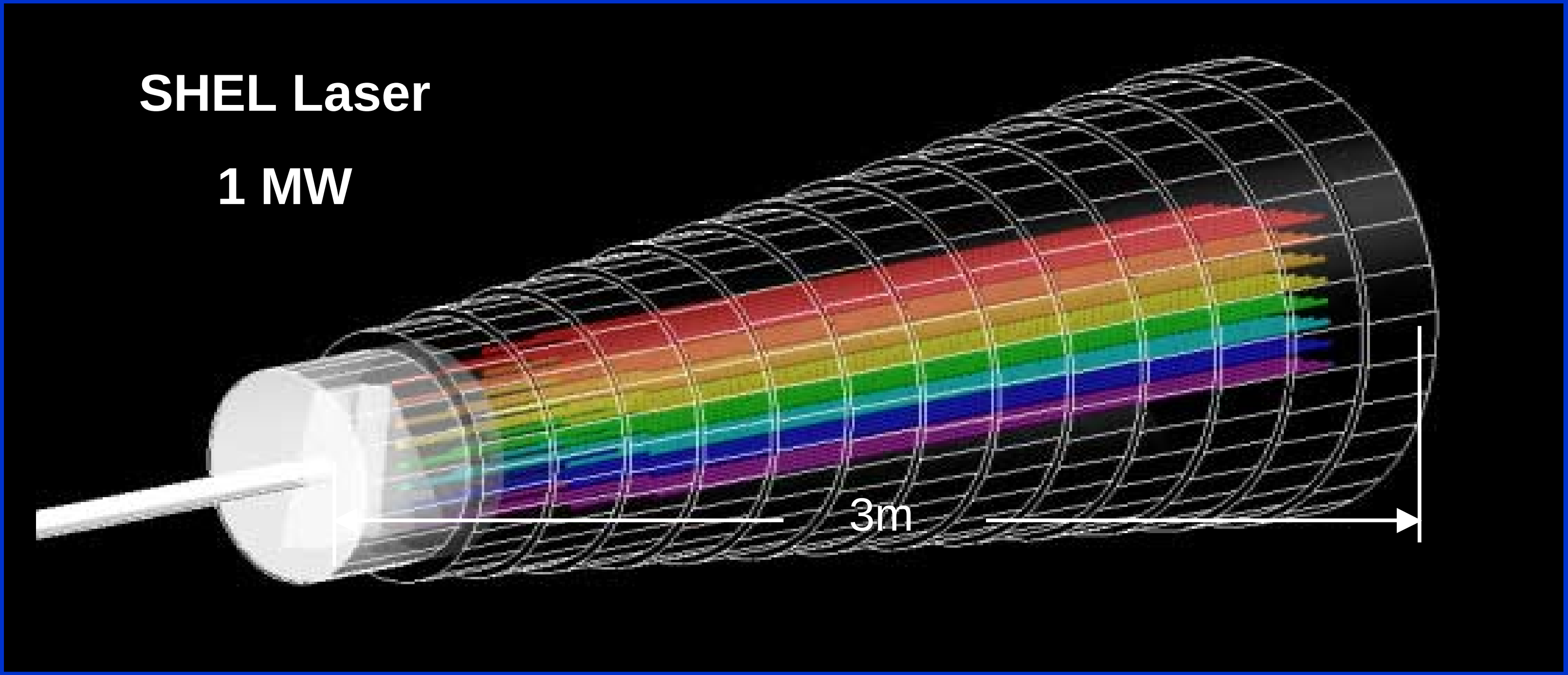


Schematic indicating the annular region filled with liquid coolant. The heat sinks (brown) on the back of the active mirrors and hermetic seal (blue) are seen in this view.

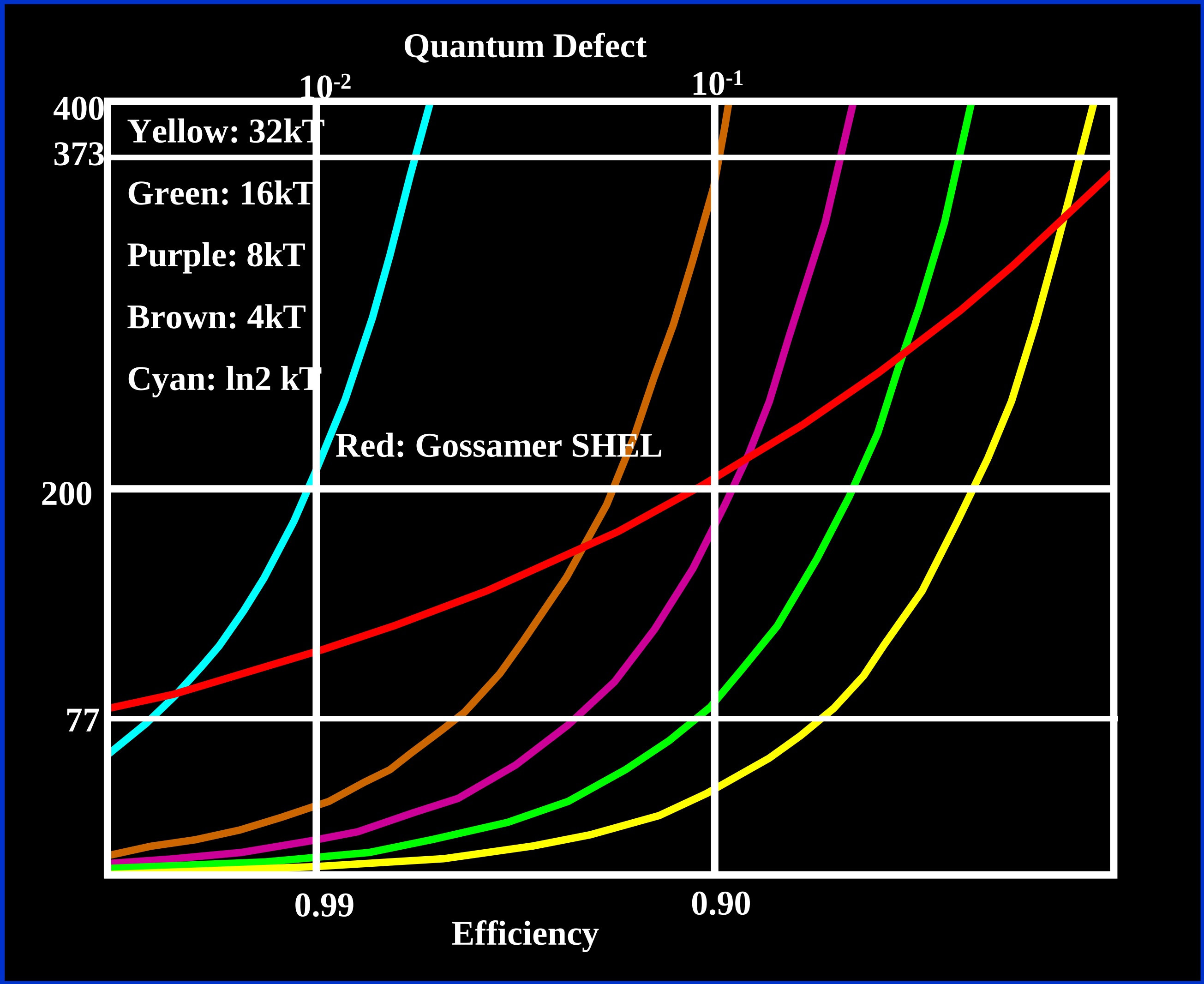
Create, in effect, a single phase coherent lowest order Gaussian laser oscillator mode folded so as to place all the heat production on a thin exterior shell.







Temperature and Efficiency Plots of Ground- and Space-Based SHEL Lasers



$$T = \left[\frac{I_S (1-\eta) A_c}{\sigma_{SB} A_e} \right]^{\frac{1}{4}}$$

Plots Describe Space SHEL using radiative cooling. The intersection points of the quantum defect curves with the red laser curve show stable operating points. The Stefan-Boltzmann equation (right) describes this form of cooling. Note that low operating temperatures are accessible at the higher efficiencies.

Space Surface High Energy Laser

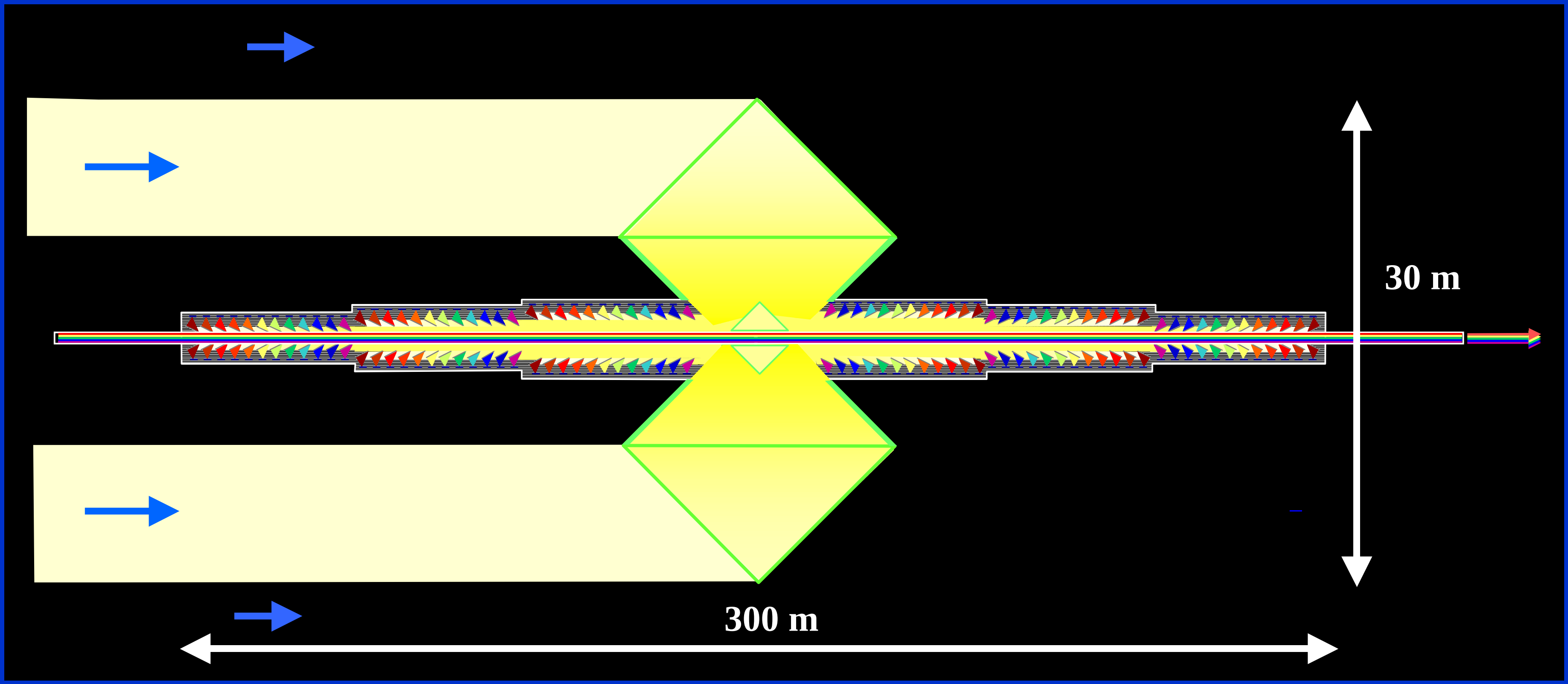


Diagram of 1 MW Space (Gossamer) SHEL that illustrates the spectral multiplexing of incoming solar radiation and the redirecting of the solar energy onto thin disks.

Ground-Based and Space-Based Systems

Both Designs Can be Scaled Up or Down, Depending on the Application

Ground-Based SHEL

Short Term (2-5 years)

Mobile

Requires Phase Change Cooling

Output Power	Size
1 kW	10 cm x 3 cm
100 kW	1 m x 30 cm
1 MW	3 m x 1 m
10 MW	10 m x 3 m

Space-Based SHEL

Long Term (10-40 years)

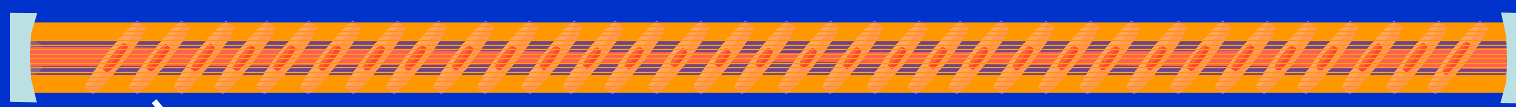
Sun synchronous Orbit

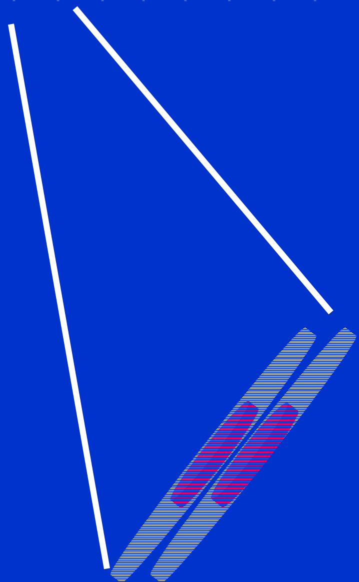
Can be Radiatively Cooled

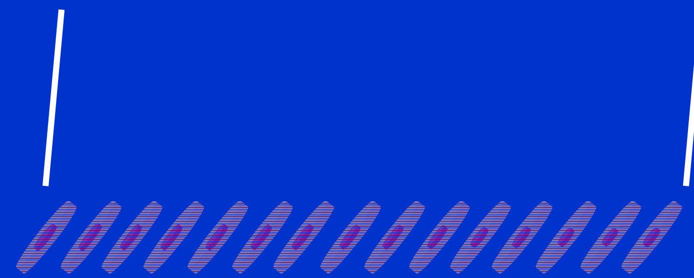
Output Power	Size
100 kW	65 m x 10 m
1 MW	200 m x 30 m
1 GW	6 km x 1 km

Both systems could be further augmented with use of optical refrigeration

Backbone Laser







White light filamentary capability directly

- Use best features of thin disk, fiber, solid state lasers
- Use precise threshold for damage to closely approach maximum intensity within laser
- Thin disk segmentation addresses B integral
- Holey fiber addresses dispersion

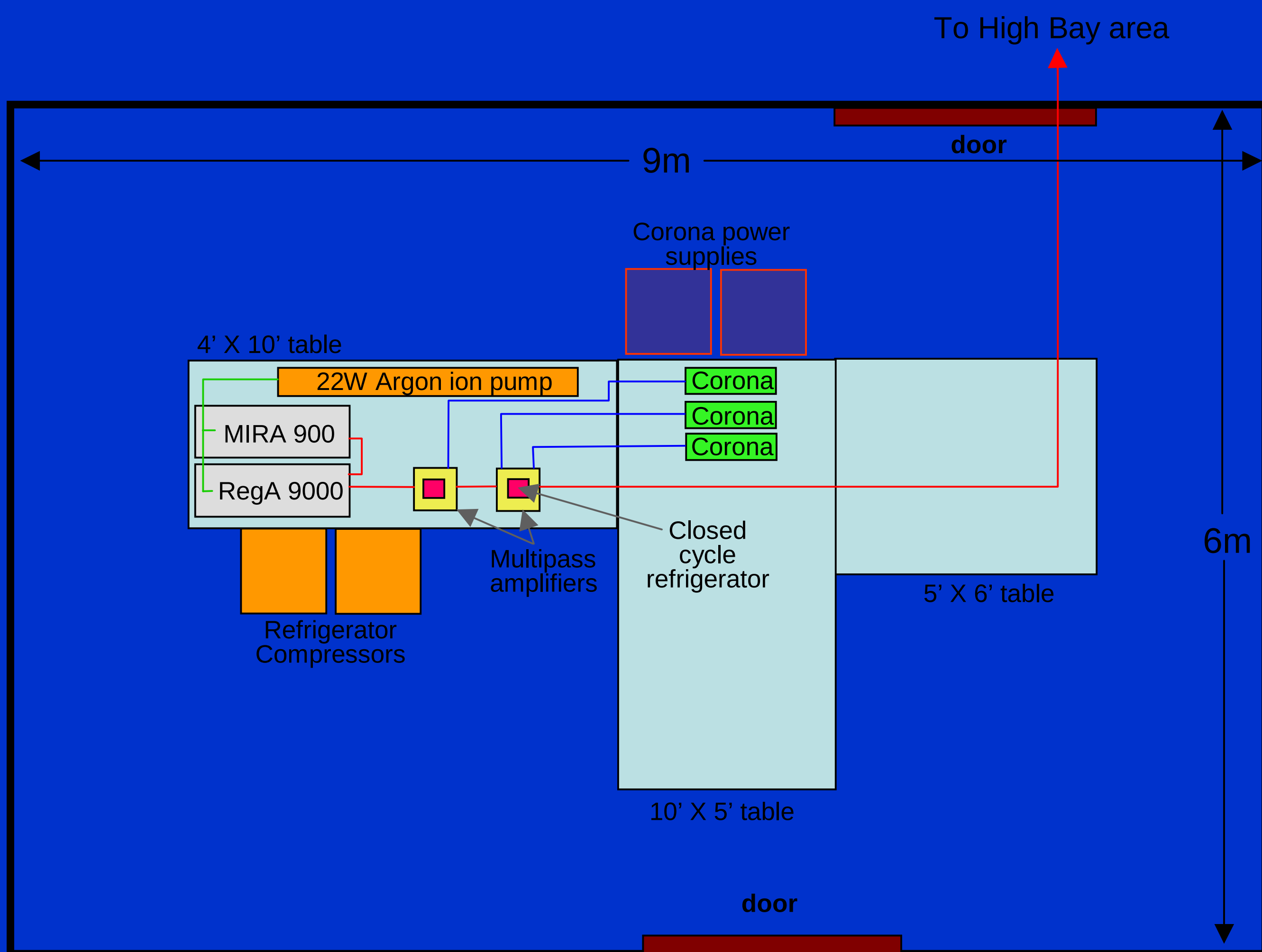
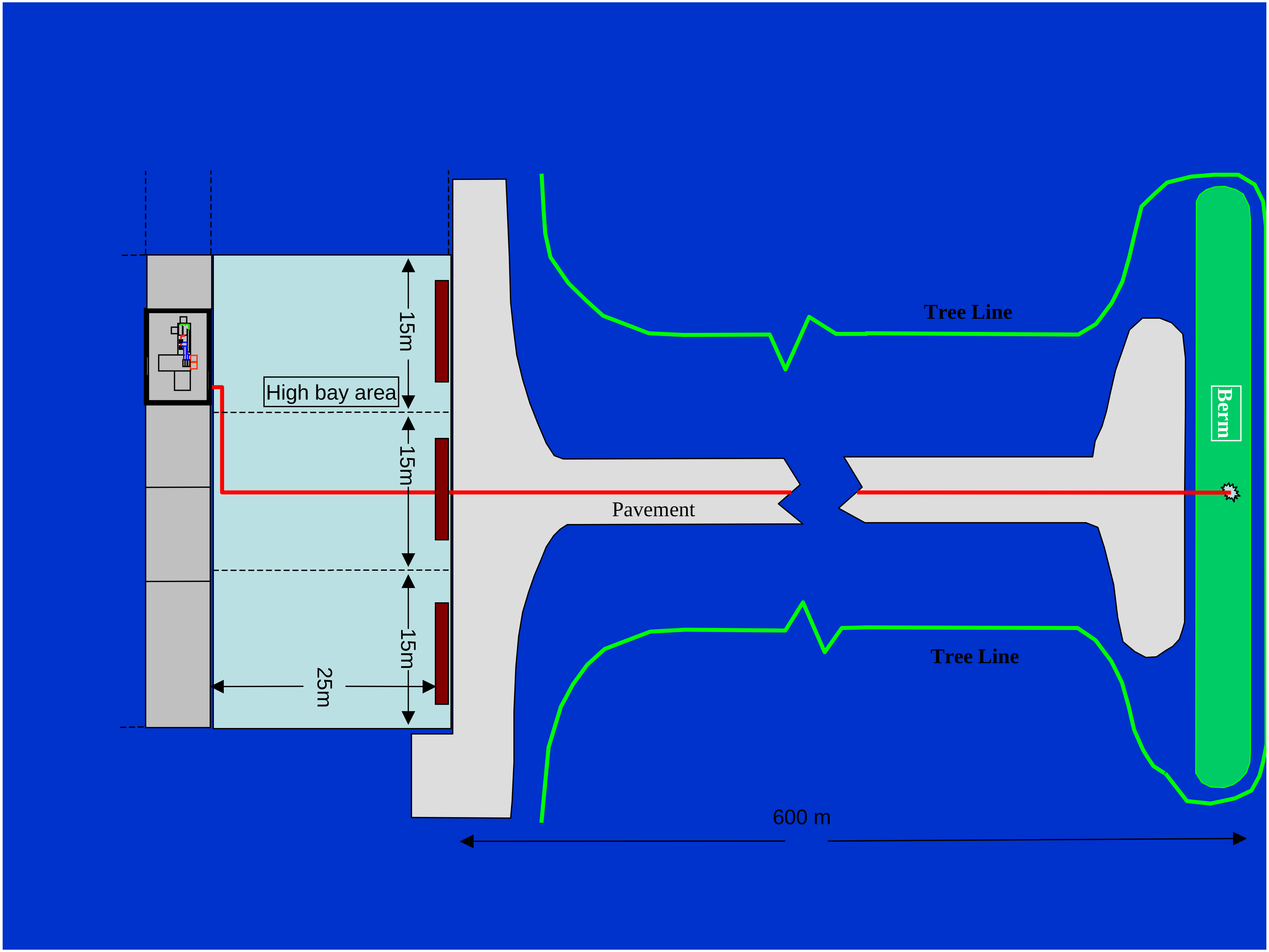


Figure 1: Laboratory setup



High bay area
15m
15m
15m
25m
Tree Line
Tree Line
Pavement
Berm
600 m

Conclusion

1. Designs focus on the best case allowed by fundamental laws, assuming quantum defect is the major source if heat.
2. Emphasis placed on moving the heat load to the outside surface of the laser; heat is carried out of the laser medium and can be rapidly removed.
3. Terrestrial system is moderate size (3m x 1m for 1 MW), which allows location on a vehicle, could be developed in the near term (2-5 years) with focused program, and can serve as a stepping stone to the space SHEL Laser.
4. Space-Based SHEL offers high average power (1 GW and more), is large, and can be used as power source. Low temperature (~200 K) and high efficiency (~0.90) offer economically viable source of clean power